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(84) Apparatus and method for positioning the point of droplet formation in the jetting fluid of an electrostatic sorting device.

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Description

Background of the Invention

The present invention relates generally to the field of electrostatic flow sorters, and more particularly to those sorters which are adapted to sense the presence and/or character of particles in a laminar flow stream and to selectively sort those particles by breaking that stream into a number of discrete droplets, and sorting those droplets containing such preselected particles. Such sorters are known for use in sorting and analyzing cellular compositions of given biological samples, as for example in the counting/analysis of cell types for a given blood sample.

In an apparatus of this general type, laminar flow is established through an area at which a light scattering, fluorescence or volume measurement is taken. Once a cell of interest has been sensed, an electronic time delay is normally activated for the length of time required for the cell to cover the distance from the point of cell detection to the point of droplet formation. Droplet formation may be accomplished by vibrating a flow chamber or orifice through which the stream passes, at a frequency sufficient to cause droplet formation, usually on the order of about 40,000 cycles per second. When a cell of interest arrives at the droplet formation point, a charging pulse may be applied to charge the droplet (plus, minus, or neutral) so that as the droplet of interest enters a subsequent DC field, it may be deflected as desired for collection. A general overview of this technique is provided in "Laser Flow Microphotometry For Rapid Analysis And Sorting Of Mammalian Cells", Mullaney, et al., Annals New York Academy of Sciences, Vol. , 197 , pages 176—190 (see in particular, pages 180 and figures 3 and 4).

Such particle sorters are also disclosed in U.S. Patents No. 3,710,933 (Fulwyler et al.) and 3,380,584 (Fulwyler) and 4,148,718 (Fulwyler). In these patents, sorting is accomplished in accordance with a selected parameter which may be size, volume presence of radioactivity, color, fluorescence, light absorption or any quality capable of being translated into an electrical quantity. These patents additionally disclose single or multi parameter measurements to effect such sorting.

In order to selectively sort those droplets containing cells which are determined to be of particular interest, apparatus of this general type generally depends upon a flow rate estimate for the fluid containing a particular cell. This flow rate estimate is used to estimate the time between cell detection and the droplet breakpoint, at which selective charging of the droplet to be sorted takes place. As disclosed in U.S. Patent No. 3,710,933, such systems are normally aligned and adjusted prior to taking cell measurements. In particular, droplet formation is normally checked by illuminating the emerging liquid jet near the flow chamber with a strobe light or equivalent light source. The strobe light is synchrofashed with respect to the oscillator frequency. Droplet

formation can then be viewed using a microscope, and by varying the voltage and frequency applied to the stream perturbing transducer, droplet formation can be adjusted for a given nozzle diameter and flow rate. See U.S. Patent No. 3,710,933, Column 11, lines 14—49.

As described particularly in U.S. Patent No. 3,710,933 (Fulwyler et al.), by pressurizing various reservoirs with known pressures, flow rates can be estimated and cell flow rate adjusted by varying the relative pressures between the various reservoirs feeding into the flow stream. The approximate time delay between cell sensing and droplet formation (which is estimated in Fulwyler et al. to be in the order of 1400 microseconds) can be estimated so that an appropriate droplet charging generator will operate in combination with a pulse height analyzer and cell separation logic to charge the selected cell containing droplets for subsequent electrostatic sorting.

A number of factors affect the ability of a given apparatus to selectively sort one or more types of target cells from a continuous cell stream. Even assuming that the detection equipment for identifying each cell to be sorted is 100% accurate, differences in flow rate, temperature, fluid viscosity, and transducer performance can affect the time delay or location of the desired target-cell-containing droplets at the breakpoint, which is the point at which a charge pulse must be administered to insure that the target cell will be subsequently electrostatically sorted.

Heretofore, one of the methods used to adjust such a sorting apparatus involves running a test sample through that apparatus which is set or programmed to sort for one or more readily identifiable cell types. According to this procedure, the delay time is manually adjusted until those droplets which are sorted from the flow stream are found to contain the expected number of target cells. While this method, used alone or in combination with the stroboscopic method discussed above, has achieved some success in this art, it is prone to a certain degree of error, particularly during periods of extended machine use and/or changing operating conditions, such as changing sample viscosities and/or temperatures.

In U.S. Patent No. 3,826,364 (Bonner et al.), a particle sorting method and apparatus are disclosed wherein a coaxial flow stream is released through a vibrating nozzle. Inspection (interrogation) of the stream by one or more cell sensing means for sensing cells in the stream occurs immediately downstream of the nozzle. In the Bonner et al. device, charging pulses are supplied at appropriate times for proper separation of the drops through the use of delay units which are adjusted to provide the necessary time delay to allow for travel time of the particle from the point of particle scatter detection to the point where the stream breaks into drops. Bonner states:

"With the present arrangement the delay time between observation of a particle and its capture by a separating droplet is predictable to within three drop periods. Such high degree of predict-

ability is due primarily to the uniform velocity of the inner particle containing stream 12A of the coaxial flow jet. That is, across the inner stream 12A the stream velocity is substantially uniform whereby particles anywhere within the cross-section of the inner stream travel with the same velocity from the point of observation to the drop separation point of the stream." U.S. Patent No. 3,826,364, Col. 7, lines 22-32.

As further explained in the Bonner et al. disclosure, the duration as well as the time of application of the charging pulse is critical to the separation of at least the droplet containing the target particle to be sorted. After describing a preferred charging pulse which will charge at least three drops, Bonner et al. states:

"Obviously, if instrument tolerances, variations, drift and like permitted, then a drop charging time sufficient to charge only two successive drops, or a single drop, could be employed." U.S. Patent No. 3,826,364, Col. 8, lines 2-6.

As also pointed out by Bonner et al., a drop breaking from a given flow stream carries with it a charge which is proportional to the potential between the droplet stream and the surrounding electrodes or charging surfaces at the time the drop separates from the stream. If the drop breaks off from the jet stream during the transition time from the drop charge pulse, either during the leading or trailing edge of that pulse, some intermediate value between zero and the desired full charge may be imparted to the target droplet. In the Bonner et al. apparatus, on/off transitions of the drop charging pulse are synchronized with the drop formation means, whereby charge pulse transitions may be synchronized to occur only intermediate the formation of droplets and not when droplets separate from the stream. This is made possible in the Bonner device by the provision of a variable phase control unit included in the transducer drive circuit which is adjusted for proper timing of droplet formation with the droplet charge pulse. As with the Fulwyler devices discussed above, stroboscopic illumination of the stream permits stream viewing through a suitable microscope, the stroboscopic illumination being synchronized by the drop charging pulses such that the stream, and more particularly the deflected drops, may be illuminated to ensure that the deflected drops contain the desired particles to be sorted.

More recently, various apparatus and method have been proposed for timing the application of a charge pulse so that droplets containing the particles to be sorted may be selectively charged. In U.S. Patent No. 3,963,606 (Hogg), a particle separator is disclosed for separating particles in a fluid according to certain particle characteristics. The Hogg device includes a means for adjusting an electrical delay to be equal to the time between the emergence of a particle from a jet forming aperture to the point of break off. Hogg proposes the use of a movable scale in place of the ground glass of prior art projection microscopes, this scale being linked to a potentiometer of an RC

oscillator to thereby control the oscillator's frequency. A second potentiometer for controlling the clock oscillator frequency is coupled to a height adjustment member of the aperture, this frequency being used to clock delay shift registers such that the charging pulse may easily be made to occur at the appropriate time, irrespective of fluctuations of pressure, velocity, amplitude and frequency of the droplet forming generator. See U.S. Patent No. 3,963,606 (Hogg), Col. 2, lines 23-36. Accordingly, Hogg represents a more automated version of the stroboscopic projection microscopic techniques discussed above.

Droplet forming characteristics in a perturbed stream have also been considered in connection with the art of ink jet printing. In the ink jet printing art, where discrete ink droplets formed in an ink jet stream are electrostatically directed to form characters on a recording surface, particular attention has been paid to establishing uniform droplet formation and charging characteristics. Since the charge imparted to any given droplet at its breakpoint is proportional to its surface area, i.e., the shape of that droplet at the breakpoint, and since even slight charge variations may produce erratic deflection characteristics, ink jet printing artisans have proposed various systems for producing an ink jet stream comprising uniformly shaped and uniformly charged droplets which will exhibit predictable down stream deflection behavior. These problems are complicated by the tendency of perturbed streams to form "satellites" which not only affect the charge imparted to preceding or succeeding droplets, but also alter the volume of those droplets, thereby correspondingly affecting print uniformity.

In the ink jet printing art, numerous systems have been proposed for sensing the characteristics of a perturbed ink jet stream, either above or below the breakpoint of that stream. U.S. Patent No. 3,907,429 (Kuhn et al.) discloses a method and device for detecting the velocity of droplets formed from a liquid stream. According to this disclosure, discrete droplets are directed between a pair of apertures and a light source which is strobed at a selected frequency and directed towards the apertures. By detecting the time between when a first of the apertures is blocked by a droplet in the stream as indicated by the light being broken during the strobe and the time when a second of the apertures is blocked by another droplet, when the light source is counted, the velocity of the droplets may be measured and a correction of the velocity made by changing the pressure of the manifolds supplying the liquid stream. In U.S. Patent No. 3,769,627 (Stone) an ink jet printing system using ion charging of droplets is disclosed wherein a light source and photocell located downstream from the breakpoint of a perturbed stream is used to sense the passage of discrete droplets and to time delayed charges subsequently applied thereto. Stone states:

"Selective drop charging involves the induction of charges in the drop being formed by a surrounding charged electrode. The induced charge

varies in accordance with the inducing voltage until the instant in time when the droplet physically separates from the stream. From that time on, the induced charge is trapped and remains with the drop. It is obvious, therefore, that the charging process must be carefully synchronized with the timing of the drop break off. This involves the use of complex phasing control sensors and loops. This in turn, increases the cost of the equipment.

* * *

It is an object of this invention to provide an ink drop charging system which does not depend upon the synchronization of the charging with the break off time.

It is another object of this invention to produce an ink drop charging system, which charges drops after they break off from the ink jet stream." U.S. Patent No. 3,769,627 (Stone), Col. 1, lines 18—35.

This method is accomplished by using the above-described photocell arrangement for the purpose of counting and synchronizing charges applied as discrete droplets pass a plurality of separate charging stations which respond to coded information applied to each station in synchronism with the passage of each drop.

As disclosed in U.S. Patent No. 4,047,183 (Taub), efforts have also been made to control the formation and shape of droplets in an ink jet stream by sensing the surface wave profile of the continuous portion of the stream (upstream from the breakpoint) by illuminating that portion of the stream with a radiant energy source such as a laser. The surface wave profile produced by illuminating the stream is sensed to provide the fundamental and harmonic frequency components thereof, and a perturbation drive signal, the amplitude and relative phase of which is a function of the sensed frequency components, is provided for controlling the formation and shape of the droplets. After discussing the advantages and difficulties of controlling the break off geometry, particularly with respect to the illumination of satellite formations, Taub discloses the practical desirability of measuring the ink jet stream upstream rather than downstream from the droplet break off point:

"The ideal time to sense the frequency, phase, and amplitude components of the ink jet stream for determining drop break off characteristics is at the precise time droplets are formed therefrom. This is usually impossible to achieve, however, since the droplets are normally formed inside the charged electrode. Therefore, according to the present invention, the drop break off characteristics are determined by sensing upstream of break off, rather than downstream as taught by the prior art. The continuous portion, that is, the portion just prior to break off of the stream is sensed to determine the break off characteristics. In response to the sensed characteristics, a piezoelectric drive signal is provided which controls droplet formation, and accordingly provides increased drop charging efficiency." U.S. Patent No. 4,047,143 (Taub), Col. 4, lines 53—68.

Taub discloses a system wherein an ink jet manifold having a perturbation means such as a piezoelectric crystal emits a perturbed ink jet stream into charge electrode structures which are pulsed in "a well known manner" to selectively apply charge to the droplets. A source of radiant energy, which may comprise a helium-neon laser, emits radiant energy focused on the continuous portion of the jet "just prior to the jet entering the charged electrode structure". "Since the ink is opaque, a shadow is formed" which is imaged through a lens onto a substrate which has a slit formed therein. The shadow formed thereby represents the surface wave profile of the jet which is a representation of the respective amplitudes and relative phases of fundamental and harmonic frequencies. Taub states:

"The light passing through the slit 44 is influenced by the wave passing a given point on the perimeter of the jet, and accordingly is a representation of the frequency components of the jet at this particular point, as well as being indicative of the shape of a given droplet when it breaks-off downstream. It is necessary to make this slit somewhat larger than the largest diameter to be measured, typically the drop diameter, so that the clipping of the wave form does not occur, as well as preventing the generation of spurious diffraction effects. A narrow band pass filter 48, which has a band pass on the order of 100 Å centered in the laser wavelength, is used so measurements may be made in room light. The light passed by the filter 48 is then transmitted to a photomultiplier tube 50 which measures the intensity of the light. Therefore, the output voltage of the photomultiplier tube 50 is proportional to the diameter of the jet blocking the slit, which is to say, to the local diameter of the jet at the point being probed. . . . It is to be appreciated that the signal output . . . may be applied to analyzing means 80 by other timing means such as a stepping motor, or alternatively may be applied concurrently to inputs of devices 82, 84 and 86, rather than in the time sequence described." U.S. Patent No. 4,047,183. See Col. 6, lines 27—68, Col. 7, lines 1—26.

In Taub's preferred embodiment, the output signal so obtained is conditioned to control the fundamental and harmonic frequencies applied to the piezoelectric perturbation means for controlling the droplet formation and shape of droplets produced by the ink jet stream.

For other disclosures of ink jet printing systems using optical sensor, see IBM Technical Disclosure Bulletin, Volume 16, No. 12, May 1974, pages 3877—8, entitled "Feedback For Synchronized Pressure Jet Using Optical Sensor"; and IBM Technical Disclosure Bulletin, Vol. 16, No. 3, August 1973, page 880, entitled "Phase Detection On Ink Jet Droplets".

For other disclosures relating to various ink jet printing synchronization systems, please refer to U.S. Patent No. 4,025,926 (Fujimoto et al.) entitled "Phase Synchronization For Ink Jet System Printer"; U.S. Patent 4,045,770 (Arnold et al.) entitled

"Method and Apparatus For Adjusting The Velocity Of Ink Drops In An Ink Jet Printer"; U.S. Patent No. 3,953,860 (Fujimoto et al.) entitled "Charge Amplitude Detection For Ink Jet System Printer"; U.S. Patent No. 3,761,941 (Robertson) entitled "Phase Control For A Drop Generating And Charging System"; U.S. Patent No. 3,836,912 (Ghougasian et al.) entitled "Drop Charge Sensing Apparatus For Ink Jet Printing System"; U.S. Patent No. 3,982,251 (Hochberg) entitled "Method And Apparatus For Recording Information On A Recording Medium"; U.S. Patent No. 3,878,591 (Eaton) entitled "Method And Apparatus For Synchronizing Droplet Formation In A Liquid Stream".

For other patents disclosing particle or flow sorting systems, please see U.S. Patent No. 3,941,479 (Whitehead) entitled "Use Of Modulated Stimulus To Improve Detection Sensitivity For Signals From Particles In A Flow Chamber"; U.S. Patent No. 3,851,169 (Faxvog) entitled "Apparatus For Measuring Aerosol Particles"; and U.S. Patent No. 3,910,702 (Corll) entitled "Apparatus For Detecting Particles Employing Apertured Light Emitting Device".

Summary of the Invention

The present invention provides a novel method and apparatus for precisely establishing and positioning the breakpoint of a laminar flow stream of an electrostatic particle sorting apparatus. By precisely controlling the breakpoint of this system, other factors, such as variable surface tension, viscosity, temperatures, etc. which could otherwise interfere with the appropriate charging of particle containing droplets, do not interfere with droplet charging synchronization.

According to the present invention there is provided an apparatus for positioning the point of droplet formation in the jetting fluid of an electrostatic particle sorting device, said device comprising:

a) flow means for establishing the flow of a continuous particle containing stream comprising at least a particle containing core stream portion and a surrounding sheath stream portion, said stream having a particle sensing point defined therealong;

b) particle sensing means for detecting said particles at least at said particle sensing point;

c) perturbation means for imparting a perturbation to said stream with at least a pre-selected frequency and amplitude to cause said stream to form a breakpoint at which said stream becomes a series of discrete droplets;

d) droplet charging means for relatively charging selected ones of said droplets as they are formed at said breakpoint; and

e) synchronization means for timing said relative charging such that said selected droplets contain at least selected particles detected by said particle sensing means; characterised by said synchronization means comprising:

i) radiant energy scatter sensing means for applying radiant energy to said stream at a sheath

sensing point subsequent to said perturbation and for sensing the radiant energy scattered by said sheath stream at said sheath sensing point, in a position such that the relative differences in the scatter of the sheath stream will cause proportional differences in the output of said radiant energy scatter sensing means, which output represents a surface character output signal;

ii) surface character analysis means for producing an output signal which depends on said surface character output signal; and

iii) amplitude adjustment means responsive to said surface character analysis means for adjusting said amplitude of said perturbation for establishing and maintaining said breakpoint at said sheath sensing point.

There is also provided according to the invention a method for positioning the point of droplet formation in the jetting fluid of an electrostatic particle sorting device, said method comprising the following steps:

a) establishing the flow of a continuous particle containing stream comprising at least a particle containing core stream portion and a surrounding sheath stream portion, said stream having a particle sensing point defined therealong;

b) detecting said particles at least at said particle sensing point;

c) perturbing said stream with at least a pre-selected frequency and amplitude to cause said stream to form a breakpoint at which said stream becomes a series of discrete droplets;

d) relatively charging selected ones of said droplets as they are formed at said breakpoint; and

e) synchronizing said relative charging such that said selected droplets contain at least selected particles detected in said detection step; characterised by said synchronizing step comprising the steps of:

i) applying radiant energy to said stream at a sheath sensing point downstream from said perturbing and producing an output obtained by sensing the radiant energy scattered by said stream at said sheath sensing point in a position such that the relative differences in the scatter of the sheath stream will cause proportional differences in said output which output represents a surface character output signal;

ii) analyzing said surface character output signal to produce an output signal which depends on said surface character output signal; and

iii) adjusting said preselected amplitude in said perturbing step in response to said selectively responsive output signal to establish and maintain said breakpoint at said sheath sensing point.

In the preferred embodiment, the radiant energy scatter sensing means comprises a radiant energy source focused on the stream to measure the scatter and extinction of said stream, and more particularly, of the sheath stream portion of that stream. The radiant energy scatter sensing means accordingly produces a surface character output signal which is proportional to the surface character of the stream, in accordance with the

preferred embodiment, perturbed laminar flow streams have been found to exhibit substantially different and distinguishable output signals when they are sensed above, below or at their break-points. Accordingly, by comparing real time waveform characteristics with a reference waveform characteristic settings, an error signal may be generated to vary the amplitude of the transducer until the breakpoint is established and maintained at the sheath sensing point. Accordingly, assuming a fixed flow rate, a given timing delay will permit the precise droplet charging of droplets containing particles identified upstream for sorting.

Accordingly, a primary object of the present invention is the provision of an improved electrostatic particle sorting apparatus wherein the breakpoint of a perturbed laminar flow stream is established and maintained at a fixed location. This and other objects of the present invention will become apparent from the following more detailed description.

Brief Description of the Drawings

Fig. 1 is a diagrammatic hybrid block drawing of the preferred embodiment apparatus of the present invention;

Fig. 2 is a representative waveform of a surface character output signal produced at the breakpoint region of a laminar flow stream;

Fig. 3 is the waveform of the surface character output signal when the sheath sensing point is located below the breakpoint of a perturbed laminar flow stream;

Fig. 4 is the waveform of the surface character output signal produced when the sheath sensing point is located above the breakpoint of a perturbed laminar flow stream.

Description of the Preferred Embodiments

Although specific forms of the invention have been selected for illustration in the drawings, and the following description is drawn in specific terms for the purpose of describing these forms of the invention, this description is not intended to limit the scope of the invention which is defined in the appended claims.

The present invention is intended for use with an electrostatic particle sorting apparatus wherein a series of particles suspended in a fluid are introduced within a sheath stream 12 to create a laminar flow stream 14. This stream is then caused to flow through a laminar flow chamber within which detection means detects particles at least at a particle sensing point, and distinguishes which of those particles are to be sorted from the stream. Said detection means may be optical detection means which comprises the use of a helium neon laser focused on the laminar flow stream 14 within the laminar flow chamber. By using various photo-optic detectors in combination with various dyes introduced in the core stream, the scatter absorption, fluorescence or other characteristics of the particles sensed at the

particle sensing point may identify those particles for subsequent sorting.

The particle detector source 16 may be a light source, a light emitting diode, helium neon laser, or laser diode. One or more particle detector receptors 18 may be oriented at one or more positions with respect to the stream, depending upon the particular type and location of energy to be detected. In the event that a particle selected for sorting has been sensed, an appropriate timing delay circuit 20 adjusted for triggering the droplet charging circuit 22 will cause the relative charging of the droplet containing the preselected particle precisely at the time that that droplet is formed at the breakpoint 26. Following the detection of the desired particle at the particle sensing point 30, the laminar flow stream issues through an orifice 28 which is perturbed by a transfer and transducer driver 32 and 34 respectively. The perturbations in the perturbed laminar flow stream 36 gradually increase in size or amplitude due to the surface tension of the jetting liquid. In accordance with the preferred embodiment of the present invention, the perturbation means, which comprises the transducer 32, transducer driver 34 and controlled amplitude oscillator 38, perturbs the stream with at least a preselected frequency and amplitude to cause the stream to form a breakpoint designated generally 26.

The synchronization means of the present invention comprises radiant energy scatter sensing means for sensing the light scatter and extinction character of the stream at a sheath sensing point subsequent to said perturbation and for producing a surface character output signal which is proportional thereto. As shown in Fig. 1, the sheath sensing point and the breakpoint correspond, the breakpoint being automatically maintained at the sheath sensing point, as described more fully hereinafter. The radiant energy scatter sensing means comprises a sheath detector source 24, which is a source of radiant energy with respect to which the sheath stream portion is essentially translucent. In the preferred embodiment, the radiant energy source may be a helium neon laser, a light emitting diode, a laser diode, or a conventional light source. The radiant energy source is focused on the stream. Suitable optics should be provided for the purpose of focusing the radiant energy upon the stream. A lens assembly comprising two cylindrical lenses has been found to be suitable for this purpose, each of these lenses having their axis oriented perpendicular to the axis of incident light, as well as perpendicular with respect to each other. It has been found suitable to utilize a front cylindrical lens having a focal length of approximately 6 mm and a back lens having a focal length of approximately 11 cm. The preferred radiant energy scatter receptor is a photodiode, but may also be a photo-multiplier. Of the above-identified lenses, the front lens tends to focus the radiant energy upon the stream, while the back lens focuses incident energy towards the diode. It has been found suitable to use a conventional FC200 Ortho Instru-

ments' lens assembly for this purpose. This lens assembly may, for example, be placed approximately 1/4 inch from the flow stream, and the photodiode placed approximately 1 inch on the opposite side of the stream past the point of focus on the lens assembly for the purpose of permitting the photodiode to pick up a substantial portion of the light neither scattered nor extinguished by the stream, but not so much light as to permit detector saturation.

In order to measure the relative scatter and extinction of the stream at the sheath detection point, the radiant energy scatter receptor 40 is located on the opposite side of the stream in a position such that the relative differences in the scatter of the sheath stream will cause proportional differences in the output of the radiant energy scatter receptor 40, which output represents a surface character output signal. In the preferred embodiment, the radiant energy scatter receptor 40 is a photodiode or, less preferably, a photomultiplier.

The surface character output signal is received by a waveform characteristics detector generator 41 which analyzes the surface character of the stream and produces its own output signal which is compared to the signal of a reference waveform characteristic setting 42 via an error signal generator 44 to produce an error signal in the event that the droplet breakpoint is found not to be at the sheath sensing point. This error signal will increase or decrease the amplitude of perturbation applied to the laminar flow stream by the transducer by acting through the aforementioned controlled amplitude oscillator 38 and transducer driver 34. In this manner, the droplet breakpoint designated generally 26 will automatically be relocated to the sheath sensing point and will be maintained in that position even in the event that other factors such as surface tension, viscosity, flow rate, temperature, orifice diameter, etc. vary during the operation of the device. In the preferred embodiment, for a given laminar flow stream, the sheath sensing point should be located so that under normal conditions the transducer amplitude is set at about 30% of its maximum amplitude, thereby permitting substantial adjustment of the amplitude in order to compensate for the above-described effects.

Referring now to Figs. 2, 3, and 4, representative waveforms are illustrated for the laminar flow stream at, below and above the breakpoint, respectively. As monitored by the radiant energy scatter sensing means, real time proceeds from left to right while the amount of light sensed by the radiant energy scatter receptor increases vertically. Referring first to Fig. 4, which is a representative trace of the perturbed laminar flow stream 36 when the sheath sensing point is located substantially above the breakpoint, the surface character output signal will be seen to be substantial sinusoidal. Peaks 100 and 102 correspond to relatively thinner portions of the perturbed stream wherein significantly lesser proportions of the radiant energy omitted by the

radiant energy source 24 are caused to scatter, and thus substantially greater portions of that energy are received by the radiant energy scatter receptor 40. Conversely, troughs 104 and 106 correspond to "bulges" or areas of relatively greater amplitude in the perturbed laminar flow stream 36, and correspondingly cause substantially greater portions of the radiant energy from the radiant energy source 24 to be scattered, and thus not received by the radiant energy scatter receptor 40. Referring now to Fig. 3 which is a surface character output signal when the sheath sensing point is located substantially below the breakpoint, that is, when discrete droplets have already been formed, each of the troughs 110 and 112 correspond to discrete droplets, slight troughs 114 and 116 to small intermediate "satellites", and the remainder of the waveform, 118 and 120, when peak amounts of light are received by the radiant energy scatter receptor, to the spaces between droplets (and/or satellites). The unique waveform shown in Fig. 2 is the waveform of the surface character output signal when the sheath sensing point and breakpoint region correspond. The spaces between droplets 122, 124, and 126 represent times when maximum amounts of light are collected by the photodiode radiant energy scatter receptor 40. The deepest troughs, designated generally 128, 130, and 132, represent the maximum bulge of the droplet to be formed. Small ripples 134 are seen to be formed in the bulge, and may be the result of harmonics in the transducer frequency, or otherwise may naturally result from the behavior of droplets at the breakpoint, which behavior is not yet fully understood. Following the bulge but still connected thereto are ligament portions which represent the rapid stretching of the tail of the bulge into a ligament which has a smaller center than ends. This ligament size and geometry blocks only about one half the light as the largest portion of the droplet. This ligament portion has broken from the preceding drop, and thus steep ligament slopes 142, 144, and 146 are evident leading to the free air spaces, such as 124 and 126, between droplets. It will be seen from the waveform at Fig. 2 that three particularly steep slopes of significant amplitude comprise the waveform at breakpoint. First, negative drop forming slopes 148, 150, and 152, positive drop/ligament slopes 154, 156, and 158, and positive ligament ending slopes 142, 144, 146. This may be contrasted with the slopes exhibited by the waveforms illustrated in Figs. 3 and 4 wherein even numbers of positive and negative slopes are observed.

In accordance with the preferred embodiment of the present invention, a certain degree of ambient light may also be collected by the radiant energy scatter receptor 40, and accordingly, troughs 110, 112, 104, and 106 are slightly flattened instead of uniformly rounded, as would be expected if ambient light were excluded from the system. Additionally, it has been found that the breakpoint waveform in Fig. 2 need not be as well defined as is illustrated in that figure, but

rather distinctive breakpoint waveforms may nonetheless be derived even if a slight defocusing of the radiant energy source 24 is permitted, thereby eliminating detection of the small ripples, such as ripples 134 and/or some of the particular details of the ligament shapes, as illustrated at 130, 138, and 140.

As recognized by one of ordinary skill in this art, small satellites such as those represented at 114 and 116 of Fig. 3 are extremely unstable, possibly due in part to their travelling in the wake of much larger spherical objects and/or other behavior caused by differential induced charges between adjacent charges. It is theorized that the shape of air flow around the larger spherical object will tend to move the satellite droplets either up or down depending upon the size, wave length and flow rate of the droplet stream. Accordingly, the waveform shown in Fig. 3 would be expected to be produced within approximately three wave lengths away from the breakpoint. As the sheath detection point is moved down, the effects of drag and flow around the sheath will become more evident, and the satellites distinguished as either "fast" or "slow" satellites. In the event, for example, that satellite 116 is a "fast" satellite, it would tend to merge with its preceding drop and accordingly would be seen to shift generally towards drop 110 until it merged therewith. Similarly, if satellite 116 were a "slow" satellite, its position will tend to shift relative toward drop 112 until it merged and was consumed by drop 112, which is the succeeding drop relative to that satellite.

In accordance with the preferred embodiment of the present invention, the waveform characteristics detector generator will analyze the surface character output signal for the purpose of determining whether that signal compares favorably with a reference waveform characteristics setting signal. While one of ordinary skill in this art will recognize from the differences in waveforms set forth in the figures that there are many parameters which could be used to distinguish the waveform of Fig. 2 from those of Figs. 3 and 4, it is presently believed that the technique disclosed in the related U.S. application of Richard A. Dussault and Igino Lombardo No. 68,112 and entitled "A Servo System To Control The Spatial Position Of Droplet Formation Of A Fluid Jet In A Cell Sorting Apparatus" is the best way of accomplishing this analysis. As more fully described in this related application, by differentiating the surface character output signal, an odd number of spikes corresponding to the three steep breakpoint spikes of substantial amplitude will be produced when the sheath sensing point is located at the breakpoint, whereas an even number of such spikes will be produced per cycle if the sheath sensing point is located either above or below the breakpoint. In either of these latter two cases, the error signal generator 44 will produce an error signal to vary the controlled amplitude oscillator and thus will act through the transducer driver 34, the transducer 32, and orifice 28 to vary the perturbation

amplitude of perturbed laminar flow stream 36. This in turn will move the breakpoint of the perturbed laminar flow stream until that breakpoint corresponds to the sheath sensing point, at which time no further error signal, and thus no further change in transducer amplitude need be effected. Assuming a constant flow rate, a fixed time delay produced by timing delay 20 will effect droplet charging through droplet charging circuitry 22 such that droplets charged at the breakpoint may be sorted through the application of an electric field created by deflection plates 200 and 202, such that the desired particles to be selected may be gathered in one of the sample collection vessels 204, 206, or 208.

From the above it will be seen that an extremely simple, yet effective method and apparatus are disclosed for precisely determining and establishing the breakpoint of a perturbed laminar flow stream at a fixed distance from the particle detection point. Assuming a fixed flow rate, an appropriate fixed timing delay will accordingly ensure precise droplet charging of droplets containing particles to be sorted.

It will be understood that various changes in the details, materials and arrangement of parts which have been herein described and illustrated in order to explain the nature of this invention may be made by those skilled in the art within the principle and scope of the invention as expressed in the following claims. As used herein, "perturbed" or "perturbation" is meant to include not only mechanical/vibratory methods for creating discontinuities in the stream, but also discontinuities which are induced by other means such as alteration of stream surface tension, for example, by electrical, thermal, or optical means. Likewise, periodic or aperiodic perturbations are meant to be included.

Claims

1. Apparatus for positioning the point of droplet formation in the jetting fluid of an electrostatic particle sorting device, said device comprising:
 a) flow means for establishing the flow of a continuous particle containing stream (14) comprising at least a particle containing core stream portion (10) and a surrounding sheath stream portion (12), said stream (14) having a particle sensing point (30) defined therealong;
- 45
 b) particle sensing means (16, 18) for detecting said particles at least at said particle sensing point (30);
- 50
 c) perturbation means (32, 34) for imparting a perturbation to said stream (14) with at least a preselected frequency and amplitude to cause said stream (14) to form a breakpoint (26) at which said stream (14) becomes a series of discrete droplets;
- 55
 d) droplet charging means (22) for relatively charging selected ones of said droplets as they are formed at said breakpoint (26); and
- 60
 e) synchronization means for timing said relative charging such that said selected droplets con-

tain at least selected particles detected by said particle sensing means (16, 18); characterised by said synchronization means comprising:

i) radiant energy scatter sensing means (24, 40) for applying radiant energy to said stream (14) at a sheath sensing point subsequent to said perturbation and for sensing the radiant energy scattered by said sheath stream (12) at said sheath sensing point, in a position such that the relative differences in the scatter of the sheath stream (12) will cause proportional differences in the output of said radiant energy scatter sensing means (24, 40), which output represents a surface character output signal;

ii) surface character analysis means (41, 42, 44) for producing an output signal which depends on said surface character output signal; and

iii) amplitude adjustment means (38) responsive to said surface character analysis means (41, 42, 44) for adjusting said amplitude of said perturbation for establishing and maintaining said breakpoint (26) at said sheath sensing point.

2. The apparatus of claim 1 wherein said amplitude adjustment means further comprises a transducer (32), transducer driver (34), and controlled amplitude oscillator means (38) for acting through said transducer driver (34) on said transducer (32) to selectively vary said amplitude of perturbation applied to said stream (14).

3. The apparatus of claim 1 or claim 2 wherein said surface character analysis means comprises a waveform characteristics detector generator (41), reference waveform characteristics setting means (42), for generating an output signal corresponding to desired waveform characteristics of the surface character output signal when the sheath sensing point is located at said breakpoint (26); and an error signal generator (44) for comparing the outputs of said reference waveform characteristic setting means (42) and said waveform characteristic detector generator (41), said error signal generator (44) comprising means for generating a proportional error signal in response to compared differences therebetween.

4. The apparatus of any one of claims 1 to 3 wherein said radiant energy scatter sensing means comprises a radiant energy source (24) with respect to which the sheath stream portion (12) is essentially translucent, and a radiant energy scatter receptor (40) for measuring the scatter of said radiant energy by said sheath stream portion (12) and for producing an output signal proportional thereto.

5. The apparatus of any one of claims 1 to 4 wherein said particle sensing means (16, 18) comprises means (18) for optically detecting said particles.

6. A method for positioning the point of droplet formation in the jetting fluid of an electrostatic particle sorting device, said method comprising the following steps:

a) establishing the flow of a continuous particle containing stream comprising at least a particle containing core stream portion and a surrounding sheath stream portion, said stream having a par-

ticle sensing point defined therealong;

b) detecting said particles at least at said particle sensing point;

c) perturbing said stream with at least a pre-selected frequency and amplitude to cause said stream to form a breakpoint at which said stream becomes a series of discrete droplets;

d) relatively charging selected ones of said droplets as they are formed at said breakpoint; and

e) synchronizing said relative charging such that said selected droplets contain at least selected particles detected in said detection step; characterised by said synchronizing step comprising the steps of:

i) applying radiant energy to said stream at a sheath sensing point downstream from said perturbing and producing an output obtained by sensing the radiant energy scattered by said stream at said sheath sensing point in a position such that the relative differences in the scatter of the sheath stream will cause proportional differences in said output which output represents a surface character output signal;

ii) analyzing said surface character output signal to produce an output signal which depends on said surface character output signal; and

iii) adjusting said preselected amplitude in said perturbing step in response to said selectively responsive output signal to establish and maintain said breakpoint at said sheath sensing point.

7. The method of claim 6 wherein said step of analyzing the surface character output signal comprises the steps of generating a current surface character output waveform, generating a reference waveform setting corresponding to a desired waveform characteristic of the surface character output signal when the sheath sensing point is located at said breakpoint, and comparing said waveforms to generate an error signal proportional to the compared differences therebetween.

8. The method of claim 6 or claim 7 wherein said step i of claim 6 comprises the steps of selecting a radiant energy source with respect to which at least the sheath stream portion is essentially translucent, focusing said radiant energy source on at least said sheath stream portion at said sheath sensing point, and measuring the scatter of said radiant energy caused by said sheath stream portion at said sheath sensing point to produce said surface character output signal.

9. The method of any one of claims 6 to 8 wherein the step of selecting said radiant energy source comprises the step of selecting a light source with respect to which said sheath stream portion is essentially translucent.

10. The method of any one of claims 6 to 9 wherein said detecting of said particles is optically performed.

Revendications

65 1. Appareil pour positionner le point de for-

mation des gouttelettes dans le jet de fluide d'un dispositif de triage électrostatique de particules, ledit dispositif comprenant:

- a) des moyens d'écoulement pour établir l'écoulement d'un courant continu (14) contenant des particules comprenant au moins une partie (10) de courant central contenant des particules et une partie (12) de courant de gaîne qui l'entoure, un point (30) de détection des particules étant défini le long dudit courant;
- b) un moyen (16, 18) détecteur de particules pour détecter lesdites particules au moins audit point (30) de détection des particules;
- c) un moyen (32, 34) générateur de perturbation pour provoquer dans ledit courant une perturbation (14) à au moins une fréquence et une amplitude présélectionnées afin de provoquer la formation par ledit courant d'un point de séparation (26) auquel ledit courant (14) devient une série de gouttelettes discrètes;
- d) un moyen (22) de charge des gouttelettes pour charger relativement certaines choisies desdites gouttelettes lorsqu'elles sont formées audit point de séparation; et
- e) un moyen de synchronisation pour synchroniser ladite charge relative de sorte que lesdites gouttelettes choisies contiennent au moins des particules choisies détectées par ledit moyen (16, 18) détecteur de particules; caractérisé par le fait que ledit moyen de synchronisation comprend:
 - i) un moyen (24, 40) détecteur de la diffusion d'une énergie rayonnante pour appliquer une énergie rayonnante audit courant (14) à un point de détection de la gaîne en aval de ladite perturbation et pour détecter l'énergie rayonnante diffusée par ledit courant de gaîne (12) audit point de détection de la gaîne, dans un emplacement tel que les différences relatives de diffusion du courant de gaîne (12) provoquent des différences proportionnelles dans le signal de sortie du moyen (24, 40) détecteur de la diffusion d'une énergie rayonnante, signal de sortie qui représente un signal de sortie de type de surface;
 - ii) un moyen (41, 42, 44) d'analyse de type de surface pour produire un signal de sortie qui dépend dudit signal de sortie de type de surface; et
 - iii) un moyen (38) de réglage d'amplitude fonctionnant en réponse audit moyen d'analyse de type de surface pour régler ladite amplitude de ladite perturbation afin d'établir et de maintenir ledit point de séparation (26) audit point de perturbation de ladite gaîne.

2. L'appareil de la revendication 1, dans lequel ledit moyen de réglage d'amplitude comprend, en outre, un transducteur (32), un circuit (34) de commande de transducteur et un moyen oscillateur (38) à amplitude commandée pour agir, par l'intermédiaire dudit circuit (34) de commande de transducteur, sur ledit transducteur (32) afin de faire varier sélectivement ladite amplitude de la perturbation appliquée audit courant (14).

3. L'appareil de la revendication 1 ou de la revendication 2, dans lequel ledit moyen d'analyse de type de surface comprend un générateur

(41) détecteur de caractéristiques de forme d'onde, un moyen (42) de réglage de caractéristiques de forme d'onde de référence pour engendrer un signal de sortie correspondant à des caractéristiques de forme d'onde désirées du signal de sortie de type de surface lorsque le point de détection de la gaîne est situé audit point de séparation (26); et un générateur (44) de signal d'erreur pour comparer les signaux de sortie dudit moyen (42) de réglage de caractéristiques de forme d'onde de référence et dudit générateur (41) détecteur de caractéristiques de forme d'onde, ledit générateur (44) de signal d'erreur comprenant un moyen pour engendrer un signal d'erreur proportionnel en réponse aux différences relatives entre lesdites signaux.

4. L'appareil de l'une quelconque des revendications 1 à 3 dans lequel ledit moyen de détection de la diffusion d'une énergie rayonnante comprend une source (24) d'une énergie rayonnante à laquelle la partie (12) de courant de gaîne est essentiellement translucide et un récepteur (40) de la diffusion d'une énergie rayonnante pour mesurer la diffusion de ladite énergie rayonnante par ladite partie (12) de courant de gaîne et pour produire un signal de sortie proportionnel à cette diffusion.

5. L'appareil de l'une quelconque des revendications 1 à 4, dans lequel ledit moyen (16, 18) détecteur de particules comprend un moyen (18) pour détecter optiquement lesdites particules.

6. Un procédé pour positionner le point de formation des gouttelettes dans le jet de fluide d'un dispositif de triage électrostatique de particules, ledit procédé comprenant les étapes suivantes qui consistent:

- a) à établir l'écoulement d'un courant continu contenant des particules comprenant au moins une partie de courant central contenant des particules et une partie de courant de gaîne qui l'entoure, un point de détection des particules étant défini le long dudit courant;
- b) à détecter lesdites particules au moins audit point de détection des particules;
- c) à perturber ledit courant à au moins une fréquence et une amplitude présélectionnées pour provoquer la formation par ledit courant d'un point de séparation auquel ledit courant devient une série de gouttelettes discrètes;
- d) à charger relativement certaines choisies desdites gouttelettes lorsqu'elles sont formées audit point de séparation; et
- e) à synchroniser ladite charge relative de sorte que lesdites gouttelettes contiennent au moins des particules choisies détectées au cours de ladite étape de détection; caractérisé par le fait que ladite étape de synchronisation comprend les étapes qui consistent:

i) à appliquer une énergie rayonnante audit courant à un point de détection de la gaîne en aval de ladite perturbation et à produire un signal de sortie obtenu en détectant l'énergie rayonnante diffusée par ledit courant audit point de détection de la gaîne dans un emplacement tel que les différences relatives dans la diffusion du courant de

gaine produisent des différences proportionnelles dans ledit signal de sortie, signal de sortie qui représente un signal de sortie de type de surface;

ii) à analyser ledit signal de sortie de type de surface pour produire un signal de sortie qui est fonction dudit signal de sortie de type de surface; et

iii) à régler ladite amplitude présélectionnée de ladite étape de perturbation en réponse audit signal de sortie sélectivement sensible pour établir et maintenir ledit point de séparation audit point de détection de la gaine.

7. Le procédé de la revendication 6, dans lequel ladite étape d'analyse du signal de sortie de type de surface comprend les étapes qui consistent à engendrer une forme d'onde de sortie de type de surface effective, à engendrer un réglage de forme d'onde de référence correspondant à une caractéristique de forme d'onde désirée du signal de sortie de type de surface lorsque le point de détection de la gaine est situé audit point de séparation et à comparer lesdites formes d'onde pour engendrer un signal d'erreur proportionnel aux différences relatives entre lesdites formes d'onde.

8. Le procédé de la revendication 6 ou de la revendication 7, dans lequel ladite étape (i) de la revendication 6 comprend les étapes qui consistent à choisir une source d'énergie rayonnante par rapport à laquelle au moins la partie de courant de gaine est essentiellement translucide, à focaliser ladite source d'énergie rayonnante sur au moins ladite partie de courant de gaine audit point de détection de la gaine et à mesurer la diffusion de ladite énergie rayonnante provoquée par ladite partie de courant de gaine audit point de détection de la gaine pour produire ledit signal de sortie de type de surface.

9. Le procédé de l'une quelconque des revendications 6 à 8, dans lequel l'étape de choix de ladite source d'énergie rayonnante comprend l'étape qui consiste à choisir une source lumineuse par rapport à laquelle ladite partie de courant de gaine est essentiellement translucide.

10. Le procédé de l'une quelconque des revendications 6 à 9 dans lequel ladite détection desdites particules est effectuée optiquement.

Patentansprüche

1. Apparat zum Einstellen des Tropfpunktes einer hervorspritzenden Flüssigkeit in einer elektrostatischen Partikelortervorrichtung, enthaltend:

a) eine Strömungsvorrichtung zum Erzeugen des Fluxus einer kontinuierlichen, partikelenthaltenden Strömung (14), enthaltend wenigstens eine partikelführenden Kernströmungsbereich (10) und einen umgebenden Hüllströmungsbereich (12), wobei die Strömung (14) einen Partikelregistrierungspunkt (30) aufweist, der an ihrer Längserstreckung festgelegt ist;

b) eine Partikelregistriereinrichtung (16, 18) zum Registrieren der Partikel an wenigstens dem Partikelregistrierungspunkt (30);

c) eine Störungseinrichtung (32, 34) zum Ver-

mitteln einer Störung auf die Strömung (14) mit wenigstens einer vorbestimmten Frequenz und Amplitude, um zu verursachen, daß die Strömung (14) einen Abrißpunkt (26) bildet, an welchem aus der Strömung (14) eine Serie einzelner Tröpfchen wird;

d) eine Tröpfchen-Ladeeinrichtung (22) zum relativen Aufladen ausgewählter Tröpfchen, wenn sie an dem Abrißpunkt (26) gebildet werden; und

e) eine Synchronisiereinrichtung zum zeitlichen Abstimmen der relativen Aufladung derart, daß die ausgewählten Tröpfchen wenigstens ausgewählte Partikel enthalten, die von der Partikelregistriereinrichtung (16, 18) festgestellt worden sind, dadurch gekennzeichnet, daß die Synchronisiereinrichtung enthält:

i) einen Strahlungsenergiestreuungsdetektor (24, 40) zum Zuführen von Strahlungsenergie zu der Strömung an einem Umhüllungsdetektorpunkt stromabwärts von der Störung und zum Ermitteln der Strahlungsenergie, die von der Hüllströmung (12) an dem Hüllendetektorpunkt zerstreut wird an einer solchen Stelle, daß die relativen Unterschiede in der Streuung der Hüllströmung (12) proportionale Differenzen am Ausgang des Strahlungsenergiestreuungsdetektors (24, 40) hervorrufen, welcher Ausgang ein Oberflächencharakter-Ausgangssignal ist;

ii) einen Oberflächencharakter-Analysator (41, 42, 44) zum Erzeugen eines Ausgangssignals, das vom Oberflächencharakter-Ausgangssignal abhängt; und

iii) eine Amplitudeneinstelleinrichtung (38), die auf den Oberflächencharakter-Analysator (41, 42, 44) anspricht, um die Amplitude der Störung einzustellen, um den Abrißpunkt (26) an dem Hüllendetektorpunkt zu erzeugen und aufrechtzuerhalten.

2. Apparat nach Anspruch 1, bei dem die Amplitudeneinstelleinrichtung weiterhin einen Wandler (32), einen Wandlertreiber (34) und einen Oszillator (38) steuerbarer Amplitude zum Einwirken über den Wandlertreiber (34) auf den Wandler (32) zum selektiven Verändern der Amplitude der Strömung (14) vermittelten Störung aufweist.

3. Apparat nach Anspruch 1 oder Anspruch 2, worin der Oberflächencharakteranalysator einen Wellenformcharakteristik-Detektorgenerator (41), eine Vergleichswellenformcharakteristik-Einstelleinrichtung (42) zum Erzeugen eines Ausgangssignals entsprechend einer gewünschten Wellenformcharakteristik des Oberflächencharakterausgangssignals, wenn der Hüllendetektorpunkt an dem Abrißpunkt (26) liegt; und einen Fehlersignalgenerator (44) zum Vergleichen der Ausgänge der Vergleichswellenformcharakteristik-Einstelleinrichtung (42) und des Wellenformcharakteristik-Detektorgenerators (41) aufweist, wobei der Fehlersignalgenerator (44) eine Einrichtung zum Erzeugen eines proportionalen Fehlersignals in Abhängigkeit zu den zwischen ihnen verglichenen Differenzen enthält.

4. Apparat nach einem der Ansprüche 1 bis 3, worin der Strahlenenergiestreuungsdetektor eine

Strahlenenergiequelle (24) enthält, der gegenüber der Hülströmungsbereich (12) im wesentlichen transluzent ist, und einen Strahlenenergiestreuungsempfänger (40) zum Messen der Streuung der Strahlenenergie durch den Hülströmungsbereich (12) und zum Erzeugen eines dieser proportionalen Ausgangssignals.

5. Apparat nach einem der Ansprüche 1 bis 4, worin der Partikelsensor (16, 18) eine Einrichtung (18) zum optischen Ermitteln der Partikel enthält.

6. Verfahren zum Einstellen des Tropfpunktes einer hervorspritzenden Flüssigkeit in einer elektrostatischen Partikelsortivvorrichtung, enthaltend die folgenden Schritte:

a) Erzeugen des Fluxes einer kontinuierlichen, partikelenthaltenden Strömung, enthaltend wenigstens einen partikelenthaltenden Kernströmungsbereich und einen umgebenden Hülströmungsbereich, wobei die Strömung einen Partikelregistrierpunkt hat, der auf ihrer Längsstreckung festgelegt ist;

b) Registrieren der Partikel an wenigstens dem Partikelregistrierpunkt;

c) Stören der Strömung mit wenigstens einer vorbestimmten Frequenz und Amplitude, um zu verursachen, daß die Strömung einen Abrißpunkt bildet, an welchem die Strömung zu einer Serie einzelner Tröpfchen wird;

d) relatives Laden ausgewählter Tröpfchen, wenn sie an dem Abrißpunkt gebildet werden; und

e) Synchronisieren der relativen Ladung so, daß die ausgewählten Tröpfchen wenigstens ausgewählte Partikel enthalten, die in der Registrierstufe ermittelt worden sind, dadurch gekennzeichnet, daß der Synchronisierschritt die folgenden Schritte umfaßt:

i) Zuführen von Strahlungsenergie zu der Strömung an einem Hülldetektorpunkt stromabwärts von der Störung und Erzeugen eines Ausgangs, der durch Messen der Strahlungsenergie erhalten wird, die von der Strömung an dem Hüllsensorpunkt zerstreut wird an einer solchen Stelle, daß die relativen Differenzen in der Streuung der Hülströmung proportionale Differenzen in dem Ausgang hervorrufen, welcher

Ausgang ein Oberflächencharakter-Ausgangssignal darstellt;

ii) Analysieren des Oberflächencharakter-Ausgangssignals zum Erzeugen eines Ausgangssignals, das von dem Oberflächencharakter-Ausgangssignal abhängt; und

iii) Einstellen der vorgewählten Amplitude in der Störungsstufe in Abhängigkeit von dem selektiv abhängigen Ausgangssignal, um den Abrißpunkt an dem Hülldetektorpunkt zu erzeugen und aufrechtzuerhalten.

7. Verfahren nach Anspruch 6, bei dem der Schritt des Analysierens des Oberflächencharakter-Ausgangssignals die Schritte umfaßt: Erzeugen einer laufenden Oberflächencharakterausgangswellenform, Erzeugen einer Vergleichswellenformeinstellung entsprechend einer gewünschten Wellenformcharakteristik des Oberflächencharakter-Ausgangssignals, wenn der Hülldetektorpunkt an dem Abrißpunkt liegt, und Vergleichen der Wellenformen, um ein Fehlersignal zu erzeugen, das proportional den verglichenen, zwischen ihnen bestehenden Differenzen ist.

8. Verfahren nach Anspruch 6 oder Anspruch 7, worin der Schritt i) von Anspruch 6 den Schritt des Auswählens einer Strahlungsenergiequelle umfaßt, in bezug auf welche wenigstens der Hülströmungsbereich im wesentlichen transluzent ist, Fokussieren der Strahlungsenergiequelle auf wenigstens den Hülströmungsbereich an dem Hüllsensorpunkt und Messen der Streuung der von dem Hülströmungsbereich verursachten Strahlungsenergiestreuung an dem Hüllsensorpunkt, um das Oberflächencharakter-Ausgangssignal zu erzeugen.

9. Verfahren nach einem der Ansprüche 6 bis 8, worin der Schritt des Auswählens der Strahlungsenergiequelle den Schritt des Auswählens einer Lichtquelle umfaßt, in bezug auf welche der Hülströmungsbereich im wesentlichen transluzent ist.

10. Verfahren nach einem der Ansprüche 6 bis 9, bei welchem das Registrieren der Partikel optisch durchgeführt wird.

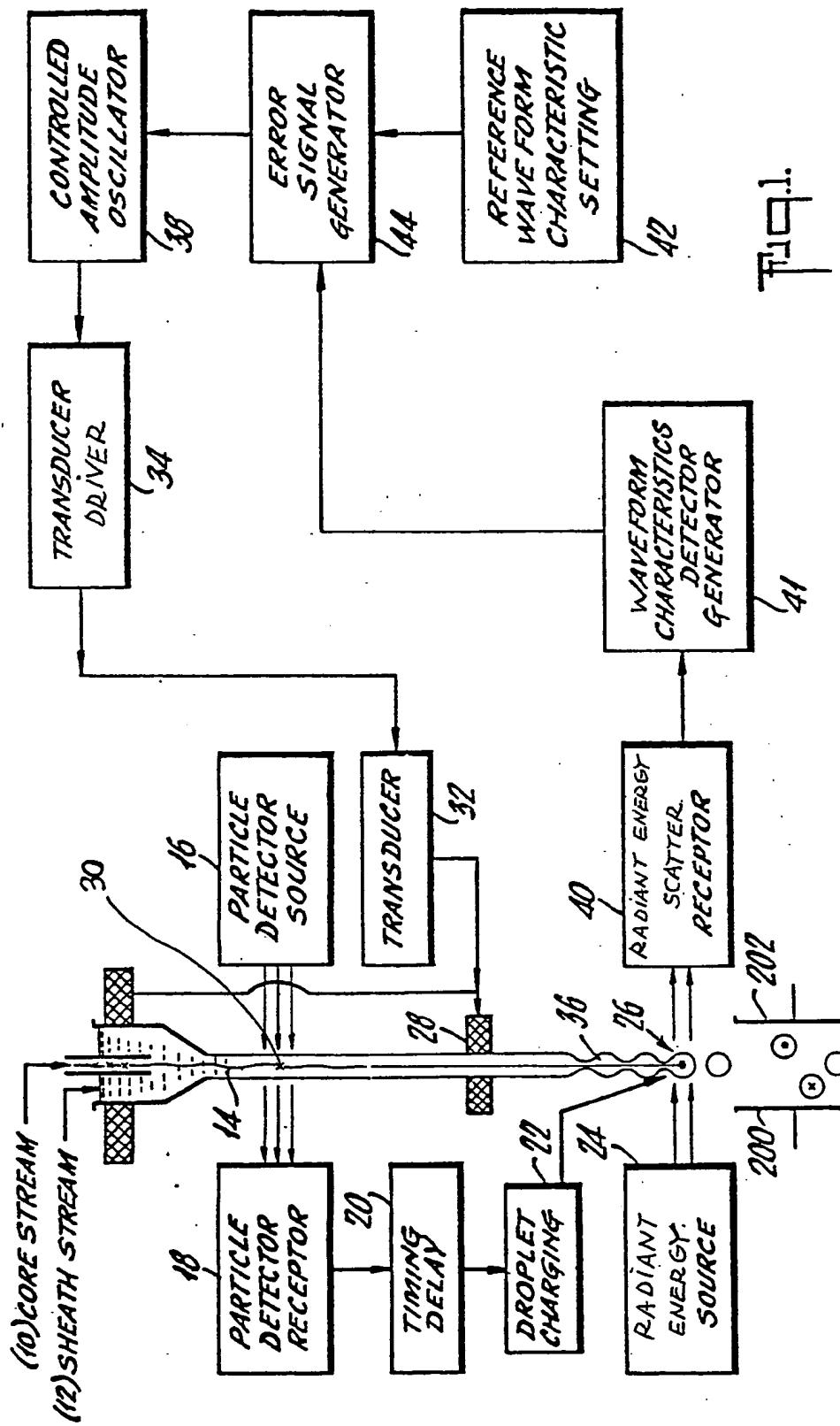


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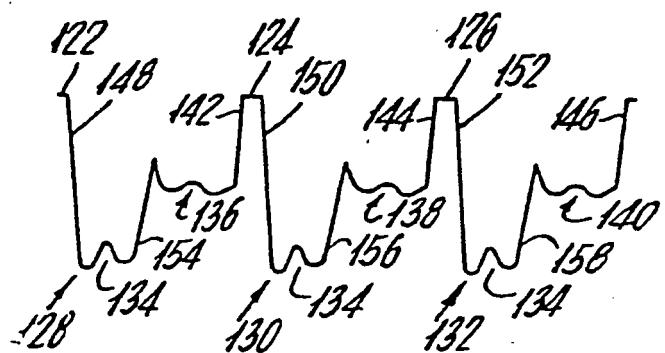


図3.

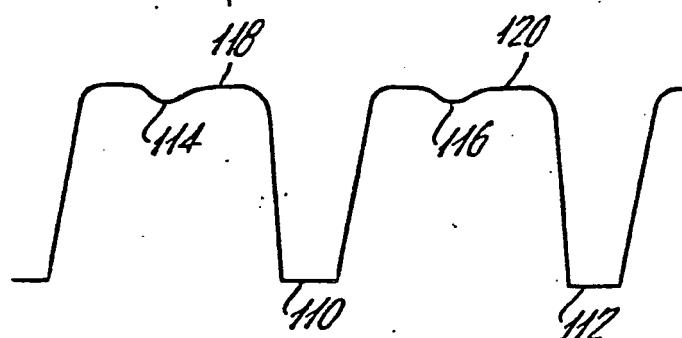


図4.

